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INFRARED ASTRONOMY

Michael G. Hauser
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, Maryland 20771

1. INFRARED ASTRONOMY

One of the lesser known contributions of Frank McDonald to space science is his role in extending high energy astrophysics to the sub-eV photon energy range—in putting infrared astronomy into orbit. This seemingly paradoxical extension was, in fact, both reasonable and timely. Reasonable, because so many infrared photons emanate from highly energetic sources such as star-forming clouds, active galaxies and the Big Bang itself. Though each photon carries modest energy, one must measure the infrared brightness to be able to understand overall source energetics. Timely, because the technical ingredients needed to make infrared space astronomy a reality, including propulsion, attitude control, cooling, and sensors, were either in hand or at least within reach.

In the spring of 1974 I was working at Caltech on new detector technology for far-infrared astronomy. I had the good fortune of having lunch one day with Len Fisk, then a member of McDonald's High Energy Astrophysics Division at Goddard. Len mentioned that Frank was thinking that it was time to start a serious effort leading toward space astronomy in the infrared, and

suggested that I contact Frank if that would interest me. I arrived at Goddard late in the summer to take up the challenge, buoyed substantially by my confidence in Frank's support and judgment, already well-confirmed in numerous other disciplines.

In addition to enthusiasm and moral support, Frank bestowed upon his fledgling effort several indispensible ingredients: talented, highly motivated people, in this case three individuals from other parts of his Division (Bob Silverberg, just completing his Ph.D. research on cosmic rays; Dave Walser, an experienced technician about to complete his electrical engineering degree; and Tony Flanick, the senior technician in the low energy cosmic ray group); funds to begin equipping a laboratory and developing hardware (I never asked him whose account he spirited this from); and space for our laboratory (those who have not worked in Building 2 cannot appreciate the magnanimity of this contribution). In his quiet, unobtrusive way Frank offered much valuable advice, ranging from whom to contact at Goddard or Headquarters to make things happen (he immediately put us in contact with Pat Thaddeus at the Goddard Institute for Space Studies (GISS), with whom we have had fruitful collaboration to this day), to how to make recruiting decisions (put talent and quality of work above specialized experience). Finally, of course, he provided a stimulating and fertile work environment, characterized by the intellectual fervor of the many research groups with overlapping scientific interests, solid engineering and software support, and unflagging management encouragement with minimal bureaucratic distraction.

That Frank's judgment was impeccable as to the proper timing for pursuit of infrared astronomy from space is borne out by the subsequent record. By the time I arrived at Goddard, NASA had announced an opportunity to propose Explorer-class missions or mission concept studies, which turned out to be the only such opportunity in the next dozen years. At that time, the infrared sky was little known at wavelengths longer than 20 microns, and was unobserved on spatial scales larger than tens of arc-minutes at any wavelength because of the bright atmospheric emission. At the long wavelength end of the infrared spectrum, there was intense cosmological interest in measuring the shape of the cosmic background radiation spectrum, then firmly established

only on the Rayleigh-Jeans side of the presumed 3 K spectrum, and in determining the anisotropy of that radiation.

With Frank's support and guidance we generated two proposals within a few months: one to conduct a sensitive sky survey at 50 and 100 microns, and the second, initiated by Pat Thaddeus and John Mather, then a young post-doc at GISS, to build a Cosmic Background Radiation Satellite to make definitive measurements of the microwave background and search for a primeval infrared background component. The latter included as collaborators David Wilkinson from Princeton and Rainer Weiss from MIT. In retrospect, these proposals were very much on target scientifically, but were programmatically remarkably naive (for example, we seriously discussed building the entire instrument complement for the cosmic background mission, including the dewar, for five million dollars!). Fortunately, the estimates became more credible, the scientific promise prevailed in the evaluation process, and the first proposal led to our participation in the Infrared Astronomical Satellite (IRAS) mission, while the second, though via a more protracted path, led to the Cosmic Background Explorer (COBE). We were suddenly caught up in the process of opening a new window on the universe, and in probing its most ancient radiative relics!

The road to completion of space programs is a lengthy one, and these two in particular have redefined the meaning of Explorer-class missions. With the wisdom of experience, and perhaps a bit of prescience, Frank from the outset encouraged us also to pursue programs which would provide both short-term scientific return and opportunities to test new technology germane to the space business. Our first such endeavor, also begun in the fall of 1974, was development of a balloon-borne telescope and submillimeter photometer for investigation of the large-scale luminosity and interstellar mass distributions in the galactic plane. With pointing control and maneuvering requirements substantially tougher than those of previous balloon payloads developed in Frank's lab, we presented a significant challenge to his engineering staff, as he no doubt wished. Their able contributions, along with those of several other engineering groups at Goddard, resulted in a payload which delivered high quality maps of the inner galaxy in each of its three flights. These data (Figure 1) show the high infrared luminosity of the inner galaxy, and, together with the data from the CO survey of the same region by Thaddeus and his colleagues,

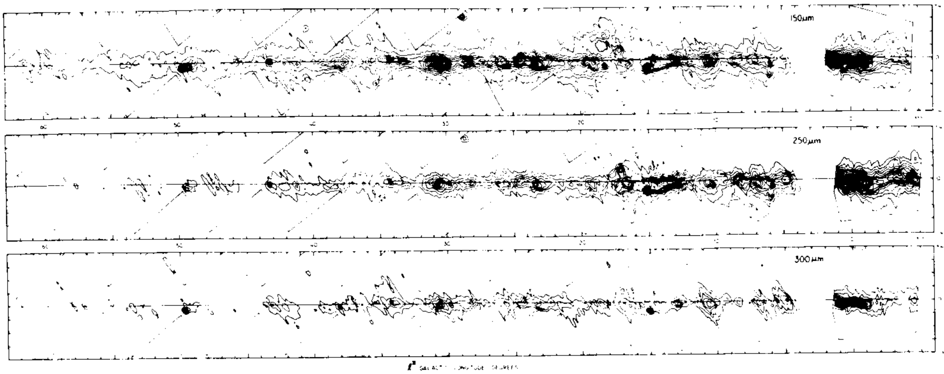

Figure 1. Contour maps of galactic plane emission at 150, 250, and 300 microns obtained with the 1.2-m diameter balloon-borne telescope developed by the Infrared Astronomy Group in the High Energy Astrophysics Division. Extensive diffuse emission is clearly evident, punctuated by discrete sources which are typically associated with prominent HII regions. Though it is generally agreed that the diffuse emission is thermal emission from dust, the location of the dust, whether predominantly associated with molecular, ionized, or atomic gas remains a question of study. [Figure originally presented by Hauser et al., 1984, Astrophys. J., **285**, *74.]*

have allowed systematic study of the distribution and properties of major star-forming regions in the galaxy [Hauser et al., 1984; Myers et al., 1986].

Subsequent to these flights, the IRAS mission did, of course, initiate the era of space infrared astronomy in spectacular fashion [Neugebauer et al., 1984; Hauser, 1986]. We have, for the first time, complete imagery of the sky in the infrared (Figure 2), including an initial determination of the heretofore elusive absolute brightness of the sky, and catalogs of hundreds of thousands of discrete sources, including tens of thousands of extragalactic objects. New insights and discoveries have emerged in wide ranging astrophysical domains, from concentrations of dust in the solar system offering clues to the origin of the interplanetary cloud, to primordial solid material orbiting nearby stars suggesting early stages of planetary system formation, and to galaxies with near-quasar luminosity emitting more than 99% of their energy in the infrared.

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Figure 2. The distribution of 100 micron emission over the full sky as measured by IRAS. This Aitoff projection is in galactic coordinates, with the galactic center at the center of the projection. The data have been filtered to suppress the very large-scale emission, such as that from interplanetary dust. In addition to the prominent emission from the galactic plane, here seen all around the sky, one sees emission from the nearby molecular cloud regions such as Ophiuchus, Orion, and Taurus, large loop structures seen also in HI maps of the galaxy, patchy clouds of emission dubbed 'infrared cirrus' by the IRAS team, and some prominent external galaxies such as the Magellanic Clouds. Space-borne cryogenic telescopes are essential to obtaining such a global view in the infrared. (Figure prepared from IRAS data by J. Good, JPL.)

The scientific harvest from IRAS will continue for many years as the astronomical community scrutinizes and ponders the data.

When NASA decided to begin serious study of the COBE mission, Frank McDonald immediately rose to the occasion by urging that we try to hire John Mather, who was then about to take a position at Bell Labs. That was probably the second best decision in the program (the first being to do it, of course!), because John could not resist the temptation to pursue the secrets embedded in the cosmic background spectrum, and has been a mainstay of the program throughout its many phases. The program not only promises uniquely exciting science, it has also, with the decision to build the instruments and spacecraft in-house, turned out to be a major contributor to the maintenance and development of Goddard's engineering capabilities. The COBE hardware is now in an advanced stage of development, and we eagerly look forward to the characterization of the cosmos which this mission will provide.

Frank McDonald's tenure as the official champion of the infrared astronomy group which he formed was relatively brief. About three years after the group was formed, we were reorganized into the Extraterrestrial Physics Division under the able guidance of Norman Ness. Frank himself subsequently left Goddard to take the position of Chief Scientist at NASA Headquarters. One might suppose that under these circumstances his contributions to our discipline have diminished. I have quite a different view. Both through intangibles, such as the quality and spirit which remain in the group which he created, and in the very tangible support and encouragement he provides for the ongoing programs established under his stewardship and for realization of the next big step in this field, the Space Infrared Telescope Facility, he continues to be a major asset to our endeavors. Frank McDonald's name may never appear on any of the research papers in infrared astronomy; nevertheless, he is leaving his mark on the field no less surely than on the many others which he has inspired and led.

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